Cold Nuclear Matter Physics

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Central Physics Questions:

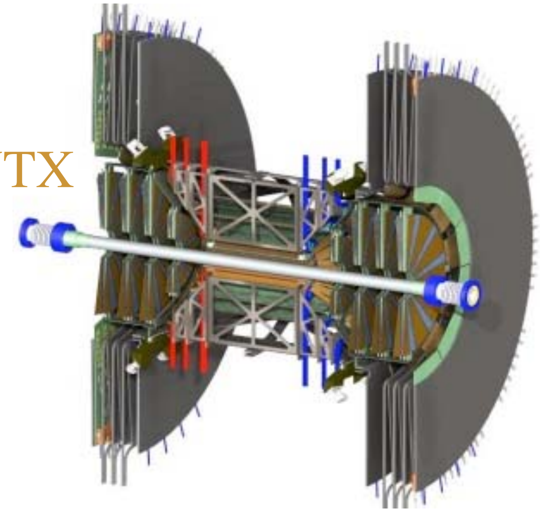
- Gluon modification in nuclei at low Bjorken-x
- Dissociation / fragmentation of quarkonia in nuclei
- Quark and gluon energy loss in nuclei
- Cold nuclear baseline for QGP Measurements

LANL PHENIX team efforts

New tools:

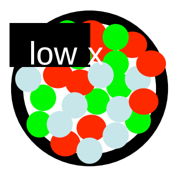
- ϕ, ρ, ω, ϒ and open heavy flavor
- FVTX detector at PHENIX
- E906 experiment at FNAL

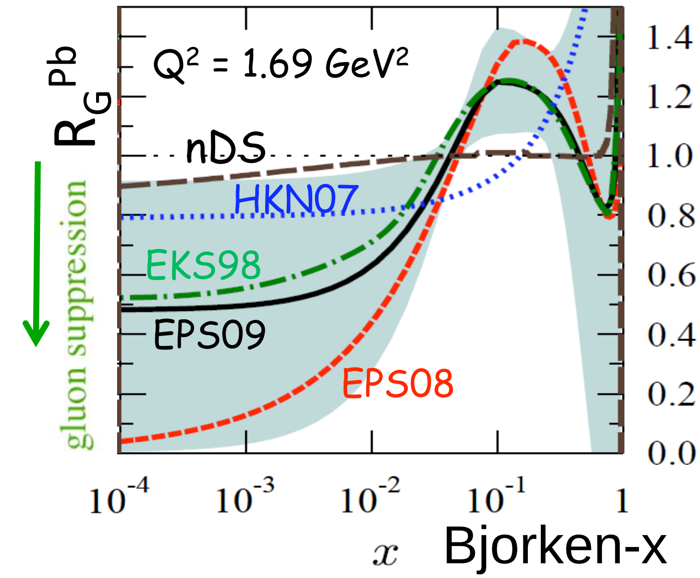
FVTX

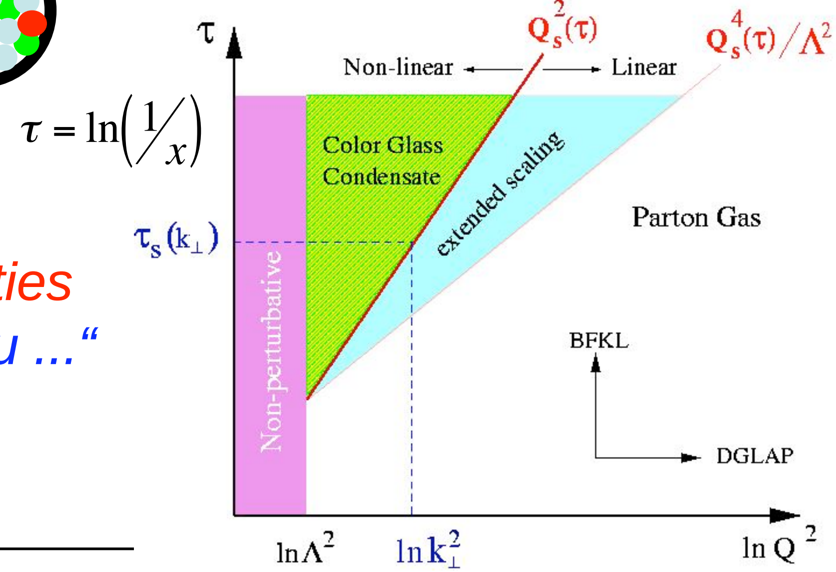


Gluon modification in nuclei at low Bjorken-x

- Leading twist gluon shadowing, e.g. EPS09 - phenomenological fit to DIS & our Drell-Yan data (E866)
- Also coherence models & higher-twist (HT) shadowing, e.g. Vitev (LANL PECASE recipient)
- Small-x gluon saturation or Color Glass Condensate. At low-x Au has ~6x higher gluon density than proton e.g. $g(x_1) + g(x_2) \rightarrow g(x_1+x_2)$ depletes the low-x gluons





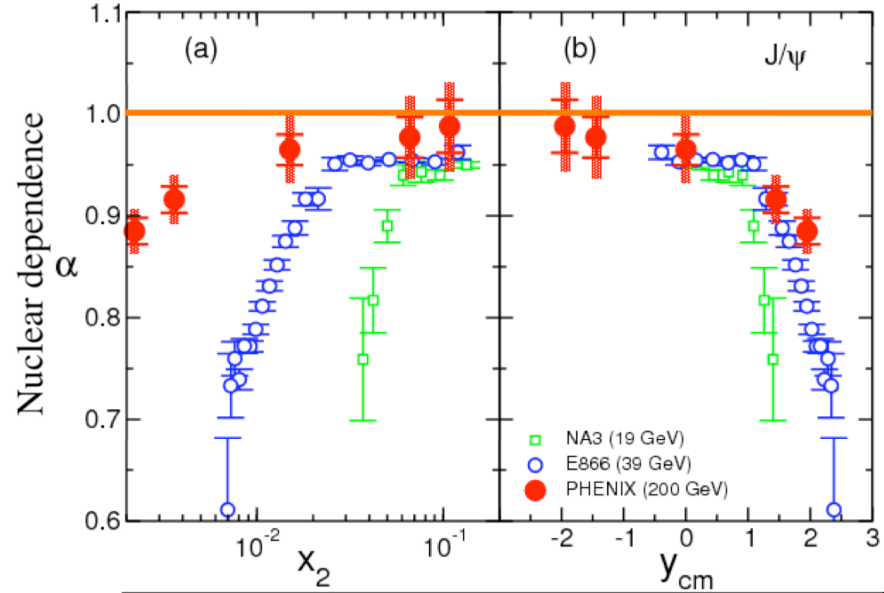


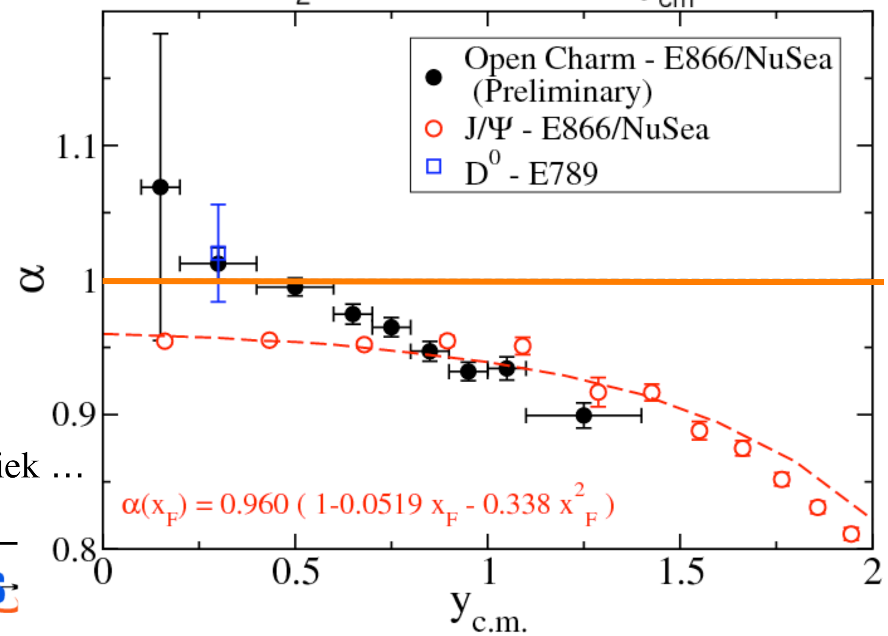
NSAC Milestone: "Determine gluon densities at low x in cold nuclei via p + Au or d + Au ..."

Dissociation / fragmentation of quarkonia in nuclei

$$\sigma_{pA} = \sigma_{pp} A^{\alpha}$$

- J/ψ is suppressed relative to open charm, due to dissociation
  e.g. J/ψ + X → D + $\overline{D}$ + X
- $\sigma_{breakup}$ ~ 4 mb
- Most apparent at central rapidity where shadowing and E-loss have little effect
- Seen also for ϒ, with smaller $\sigma_{breakup}$ due to 2 x smaller size object
- FVTX will enable direct open charm and beauty measurements at PHENIX



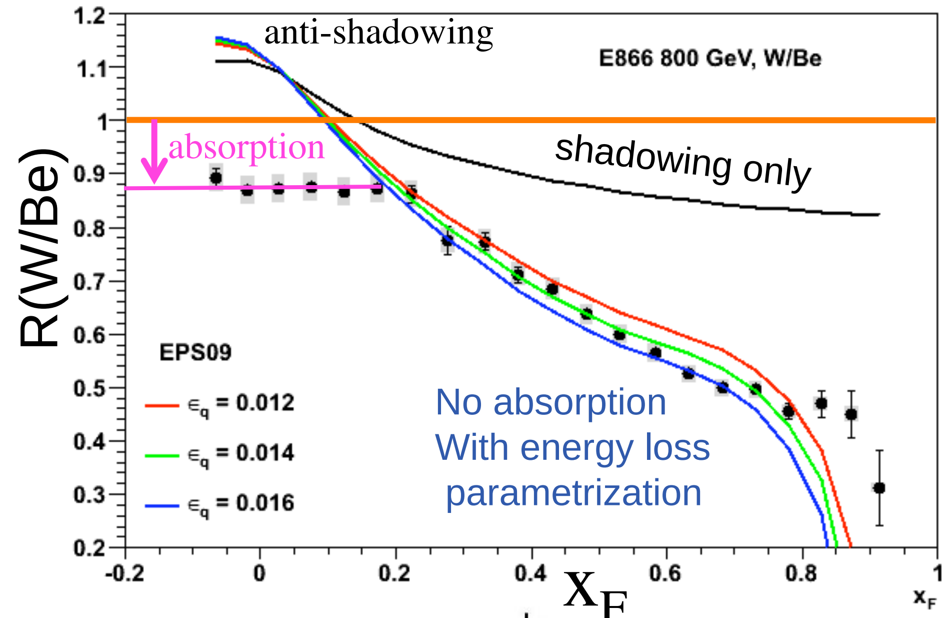


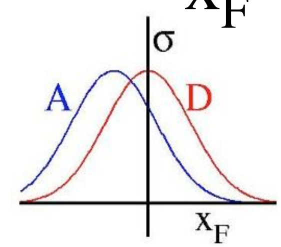
E789, 866 data – Leitch, McGaughey, Klinksiek …
PHENIX data - Leitch, Pereira, …

Quark and gluon energy loss in nuclei

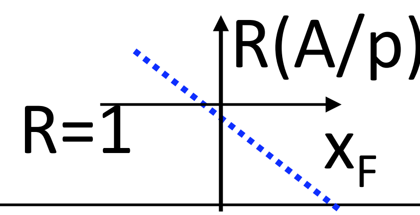
- Absorption plus shadowing cannot account for suppression of J/ψ at forward rapidity
- Missing piece is energy loss
- Large effect, Δp/p ~10%! Energy loss significant even at large momenta
- Need to understand E-loss in CNM as a baseline for probing QGP

E866/NuSea, 800 GeV, J/Ψ p+W / p+Be ratio



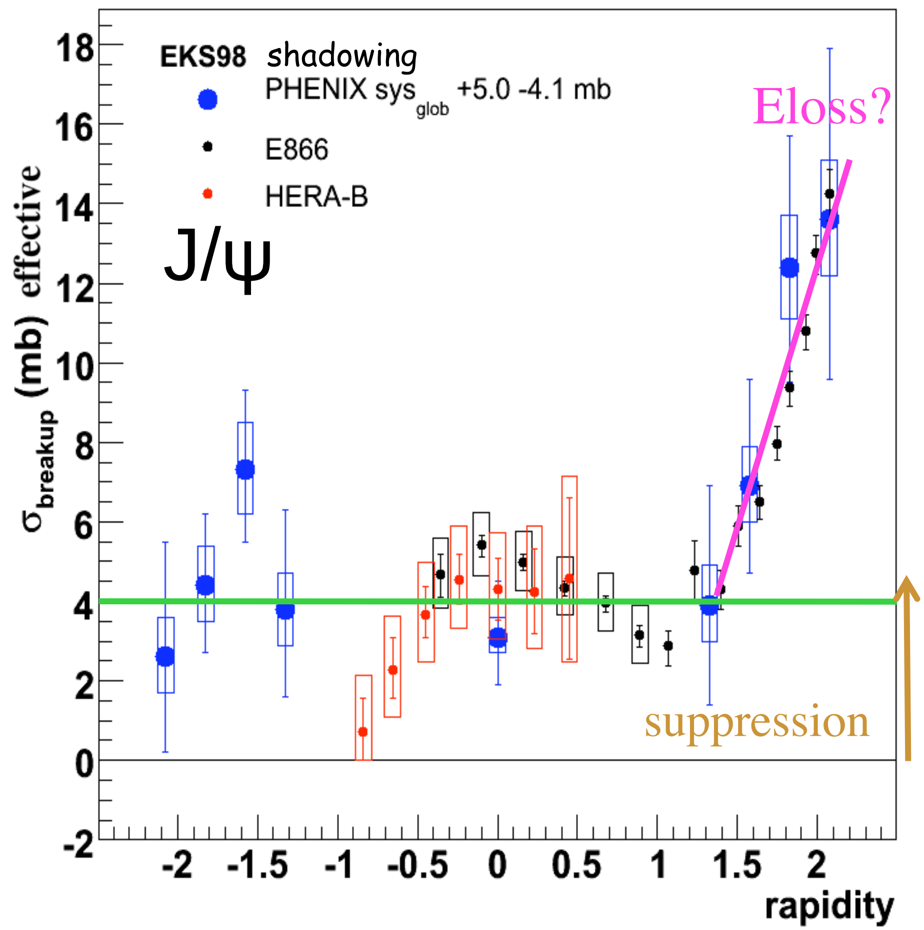


Related to NSAC Milestone: "… constrain the mechanism for parton energy loss in the quark-gluon plasma."



Energy loss, contd.

- Nearly constant effective breakup cross section for J/ψ, except at forward rapidity
- Forward region has large additional suppression, likely due to energy loss
- Measurements from fixed target and collider energies in good agreement



PHENIX data - Leitch, Frawley, …
E866 data – Leitch, McGaughey, …

Energy loss in cold nuclear matter is unknown!

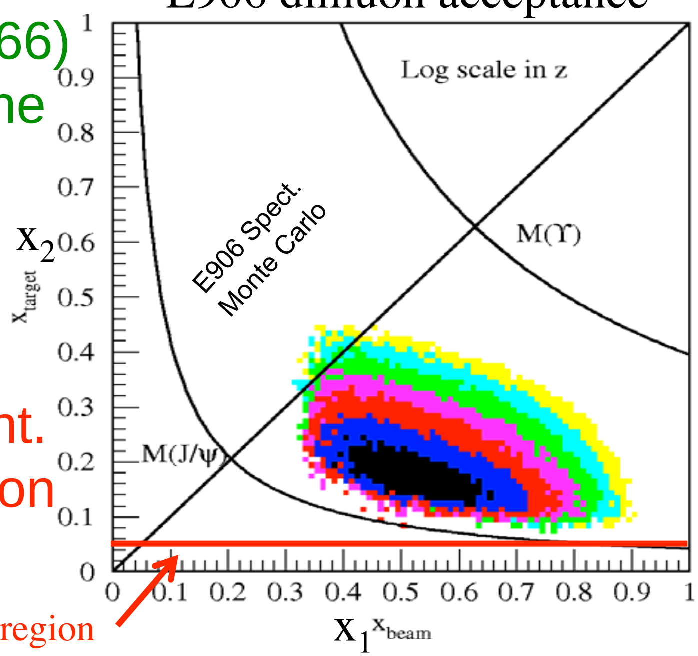
- Theoretical form of energy loss is unclear - fundamentally different than pure E-M e-loss. linear or quadratic dependence on path length? radiative or collisional energy loss dominant?

$$\frac{\Delta E}{E} \propto \frac{L}{\lambda_g} \ln \frac{E}{Q_0} \quad \text{or} \quad \frac{\Delta E}{E} \propto \frac{\mu^2 L^2}{\lambda_g} \frac{\ln E / Q_0}{E}$$

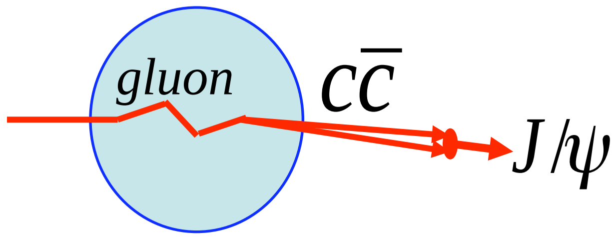
from Vitev

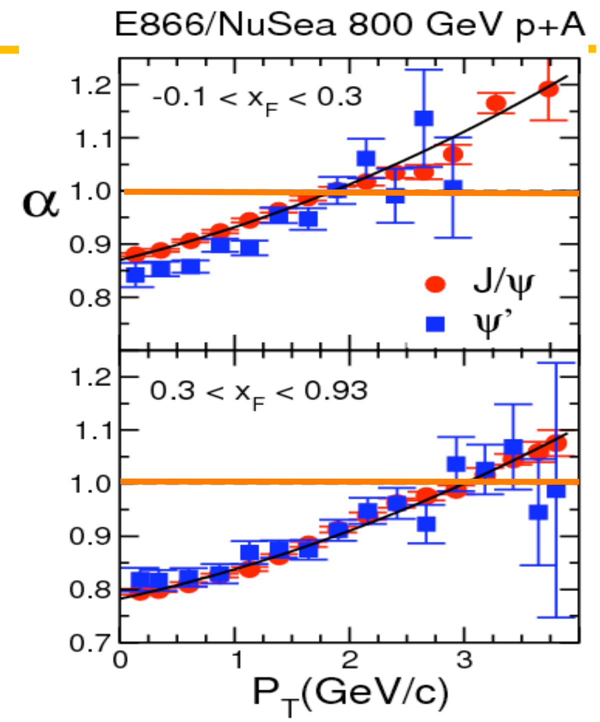
- Experimental bounds from Drell-Yan (E772,E866) range from 0 to ~2.3 GeV / fm, depending on the amount of shadowing
- Energy loss in nuclear matter is baseline for measurements of QGP formation
- E906 at FNAL will make definitive measurement. Lower beam energy eliminates shadowing region

E906 dimuon acceptance



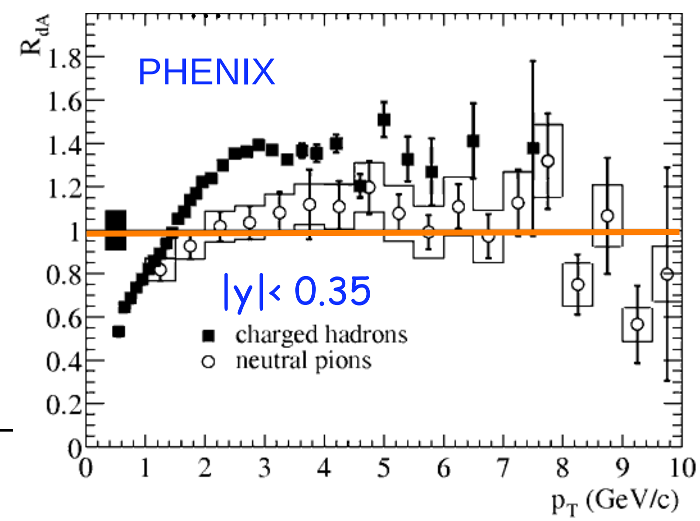
Cronin Effect in p,d + A Collisions





E866 data – Leitch, McGaughey

- p_T broadening from soft initial and final state scattering
- Increases $\langle p_T \rangle$, suppressing yield at low p_T and enhancing at high p_T
- A measure of multiple scattering, weakly connected to energy loss
- Universal process seen in Drell-Yan, J/ψ, ψ', ϒ, etc. production in nuclei



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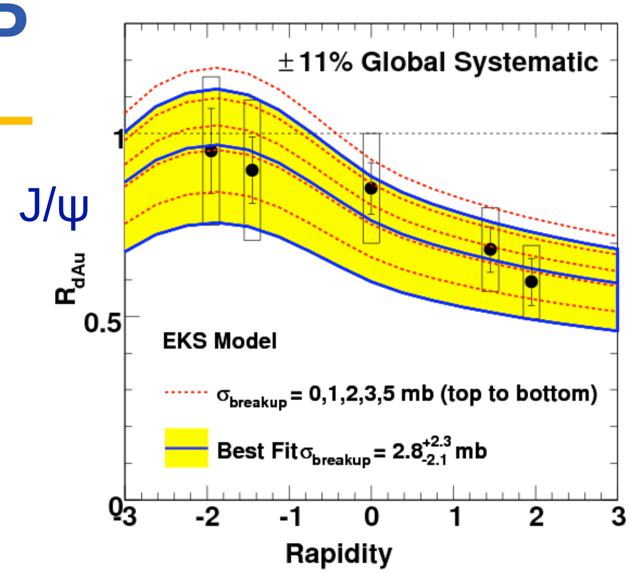
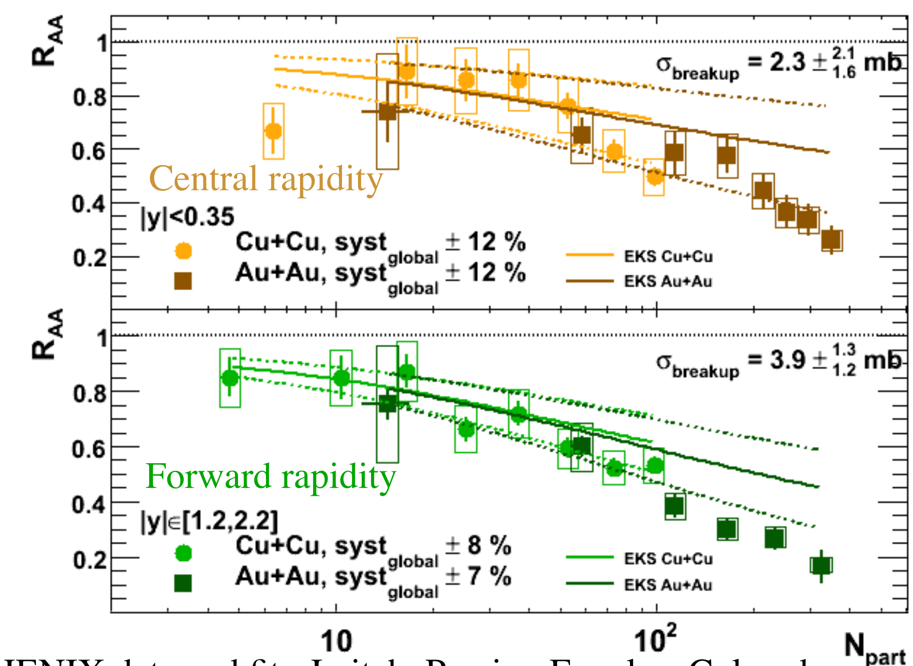
Physics

Cold Nuclear Baseline for QGP

- Extrapolate phenomenological fit to J/ψ suppression from 2003 d+Au to estimate CNM baseline for Au+Au
- Excess suppression over CNM seen in Au+Au at forward and central rapidities for large N_{part}
- Suppression is stronger at forward rapidity
- CNM effects on J/ψ production are very important!





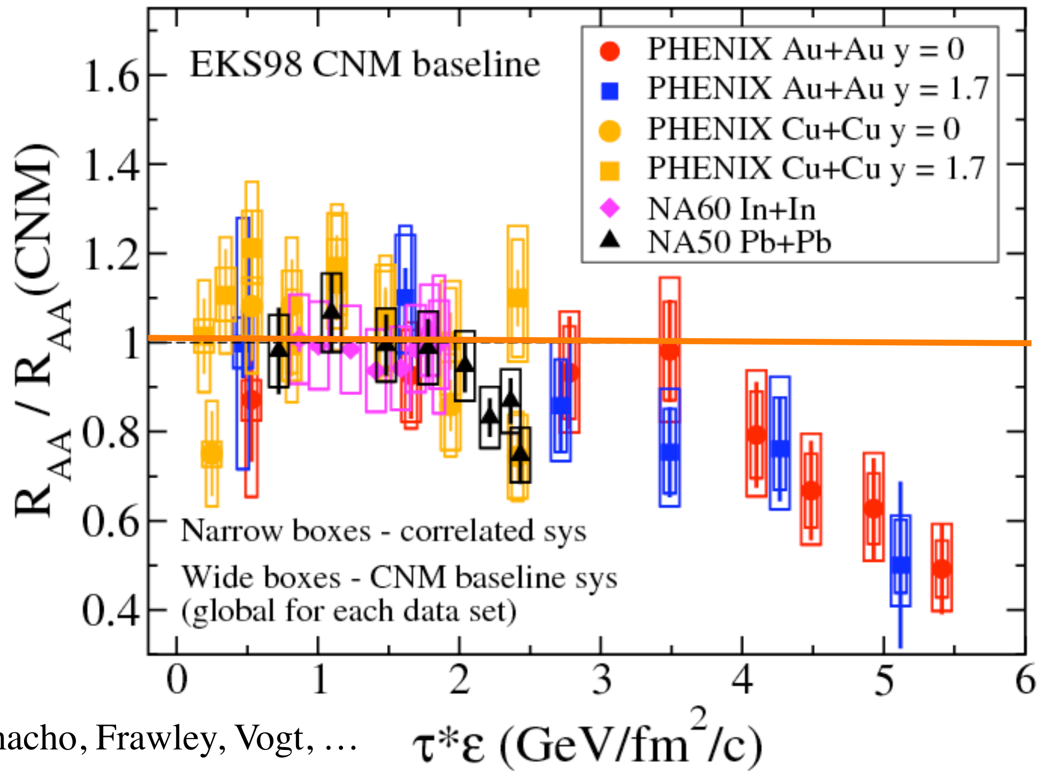
PHENIX data and fit - Leitch, Pereira, Frawley, Colorado

Cold Nuclear Baseline for QGP, contd.

- Recent Comparison of J/ψ Suppression of RHIC (2004, 2008) & SPS in A+A Collisions (QGP) after dividing out d(p)+A CNM baselines
- Excess suppression over CNM clearly seen at highest energy density
- Much stronger effect at RHIC than SPS!

Use tau*energy density scale

Not a PHENIX Result
Uses Preliminary PHENIX d+Au RCP (QM09)

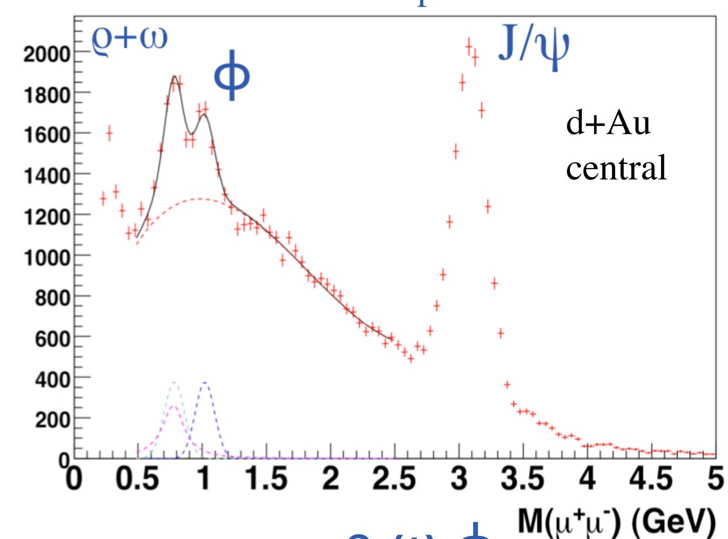


From Leitch, Camacho, Frawley, Vogt, …

φ, ρ, ω, ϒ → $\mu^+ \mu^-$

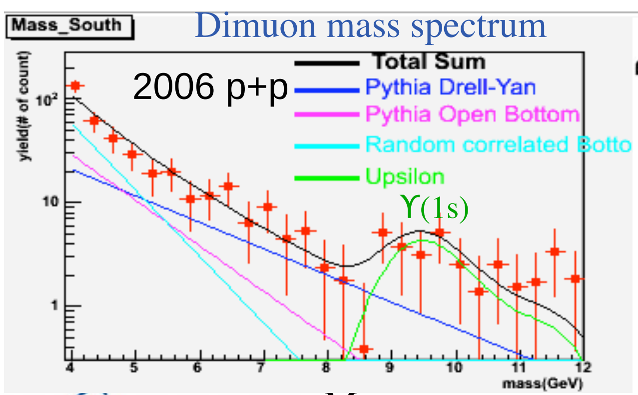
- Both φ and ϒ now observed at RHIC in dimuon channels from p+p and d+Au
- φ R_{CP} behaves similar to J/ψ, strongly suppressed at forward rapidity, not at backward
- Preliminary measurement of ϒ cross section and R_{dA} versus rapidity, will improve as luminosity increases

Dimuon mass spectrum

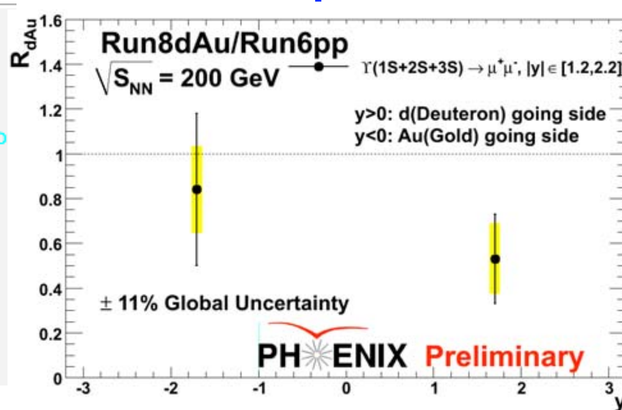


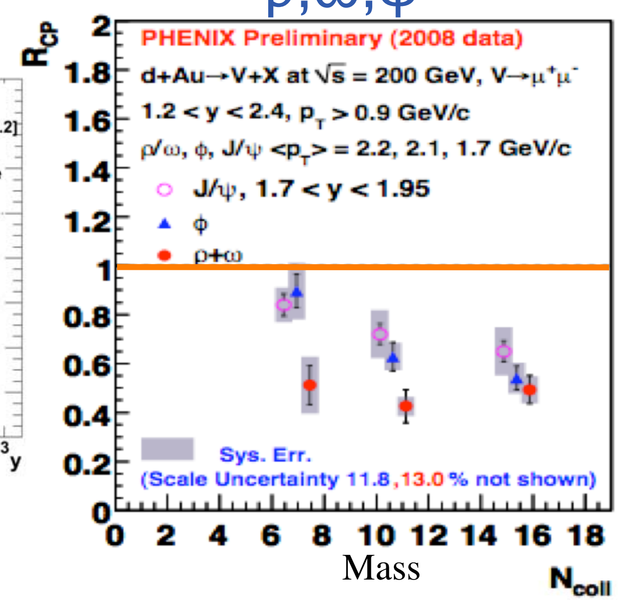
ρ,ω,φ

ϒ



Mass





Mass

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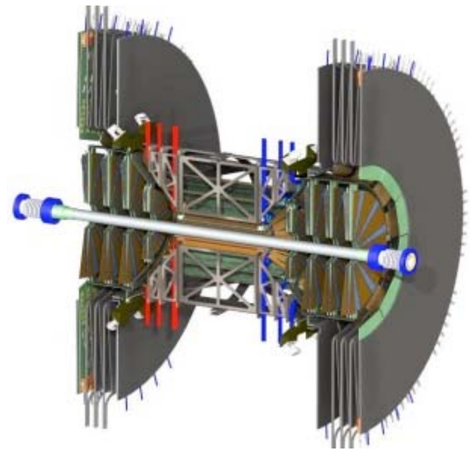
PHENIX data – Guo, Leitch, K. Lee, …

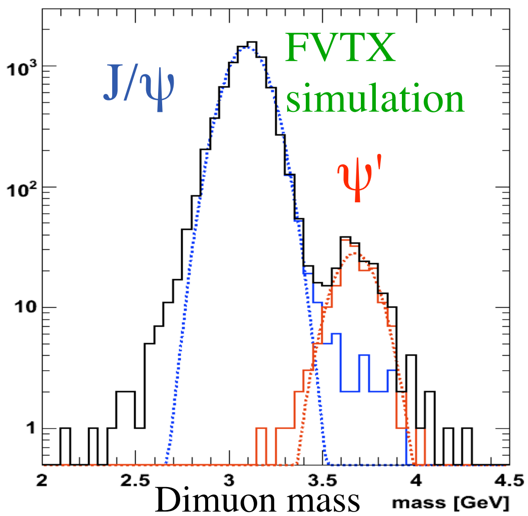
Patrick L. McGaughey

New Physics with FVTX at PHENIX

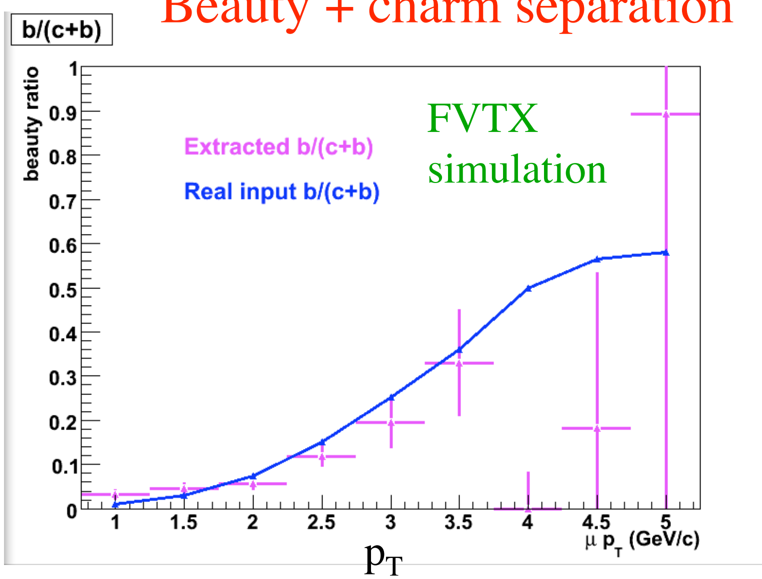
- Direct identification of D, B → μ + X and B → J/Ψ
  → energy loss and shadowing for D,B mesons
  direct access to gluon structure
- Improved J/ψ and ψ' mass resolution
  → enable use of ψ' as a probe
- Reduced backgrounds by rejection of π and K
  → enable W and Drell-Yan measurements
- Installation in summer of 2011



ψ' separation possible



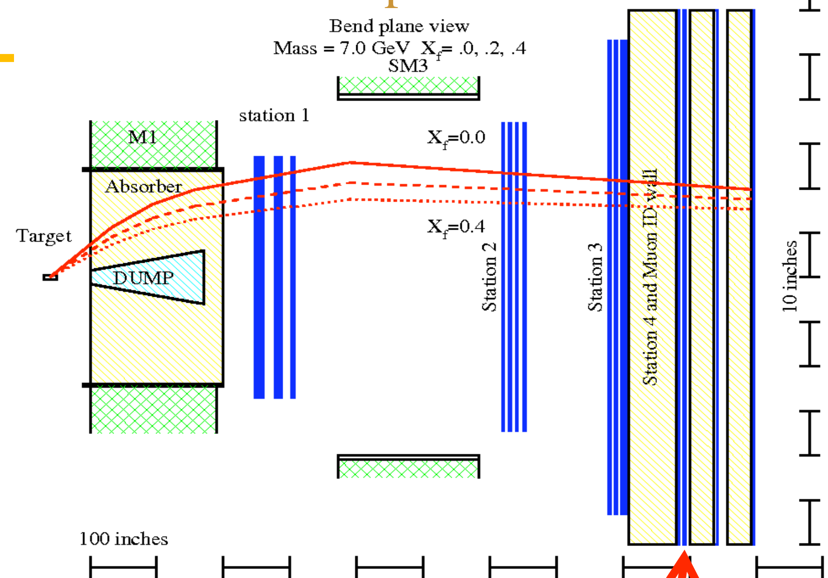
Beauty + charm separation

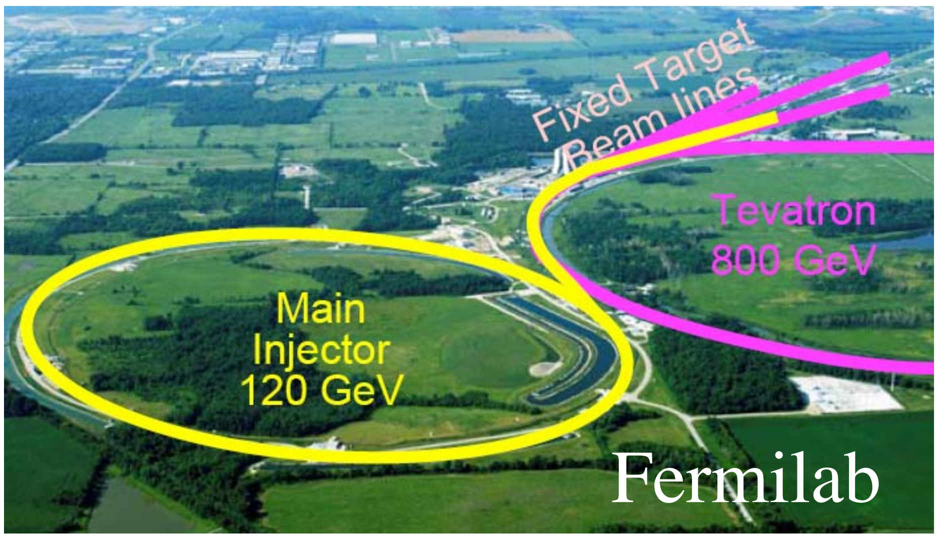


E906 experiment at Fermilab

- Quark energy loss form and strength
- Improved $\bar{d}/\bar{u}$ at large x with Drell-Yan from 120 GeV proton beam
- Separation of shadowing from energy loss
- LANL leading E-loss and muon ID

Schematic of new E906 spectrometer





800 Muon Identifier Tubes from LANL
~$1M contributed by muon radiography

E906 Sensitivity to Quark Energy Loss

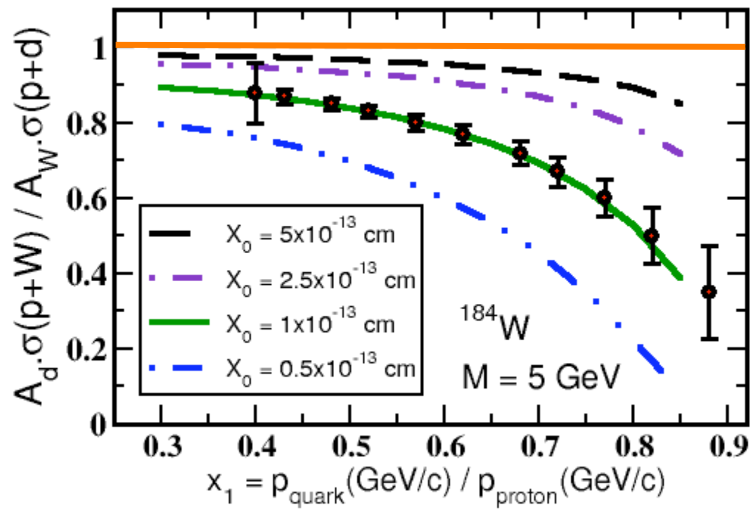
- Use suppression of Drell-Yan production at large x_1 to infer initial-state CNM energy loss
- For radiation lengths $X_0 = 1 \times 10^{-13}$ m can achieve sensitivity ~ 20%

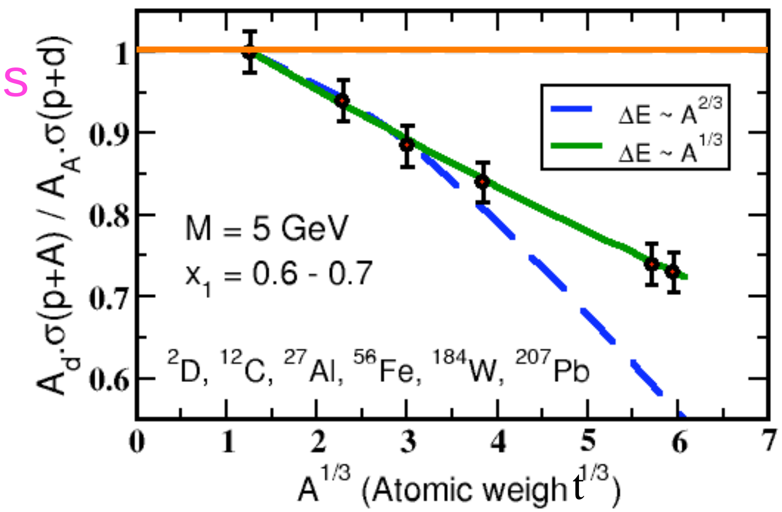
- Clearly distinguish between leading models for L dependence of E-loss (5σ):

$$-\Delta E \sim A^{1/3} \;(\text{or} \;\sim L)$$

$$-\Delta E \sim A^{2/3} \;(\text{or} \;\sim L^2)$$

Simulated Quark energy loss only





from Vitev, Liu

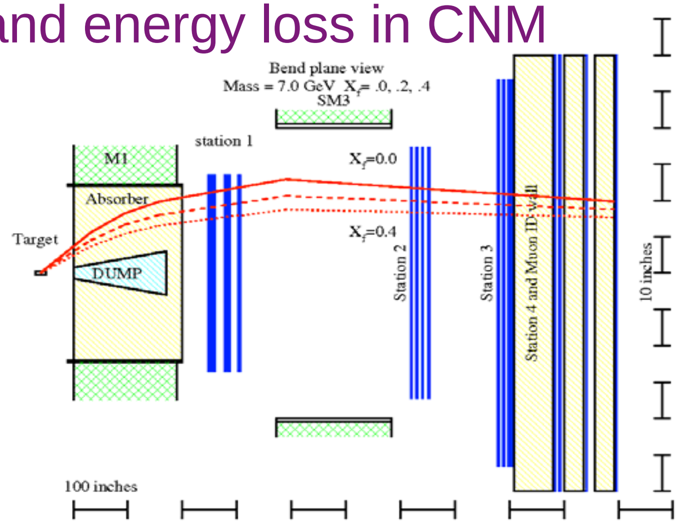
Cold Nuclear Matter Physics Outlook

Highlights at PHENIX:

- Full suite of measurements becoming available with dimuons -
  ϕ, ρ, ω, J/ψ, ψ’, ϒ, Drell-Yan, B and D mesons
- Addressing shadowing, saturation, dissociation and energy loss in CNM

Highlights at future E906:

- quark energy loss to 20%, path length and
  energy dependence
- $\bar{d}/\bar{u}$ at $x \leq 0.5$
- bound on orbital angular momentum
- LANL muon identifier, installation 2010



FVTX construction, led by LANL:

- Installation in Summer, 2011
- Greatly improves heavy quark ID, mass resolution
  and background in dimuon continuum